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The computer program Interactive Contouring from an Irregular Triangular Grid (ICFITG) allows the program user to make judgements during the preparation or modification of an isarithmic map. This is accomplished interactively through the use of virtual images and devices, character commands and responses, and audio signals such that the cartographer can make decisions that affect the outcome of the final map while the program is executing. It is interactive computer graphics that form the link

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ICFITG: A PROGRAM FOR INTERACTIVE CONTOURING FROM AN IRREGULAR TRIANGULAR GRID

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BIOGRAPHICAL SKETCH

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Harold Moellering received his Ph.D. from the University of Michigan and is currently Associate Professor of Geography at Ohio State University. His research interests include computer methods in cartography, numerical cartography, cartographic animation, and geographic information systems, and has published a number of papers pertaining to these topics. Dr. Moellering is a member of ACSM, AAG, BCS, CCA, and ACM and is a member of the editorial board of the American Cartographer.

ABSTRACT

The computer program Interactive Contouring from an Irregular Triangular Grid (ICFITG) allows the program user to make judgements during the preparation or modification of an isarithmic map. This is accomplished interactively through the use of virtual images and devices, character commands and responses, and audio signals such that the cartographer can make decisions that affect the outcome of the final map while the program is executing. It is interactive computer graphics that form the link between the speed and repetitive processing power of the computer and the decision making power of the cartographer. The computer program ICFITG incorporates a contouring algorithm which is based on the formation of an irregular triangular grid. The use of such an algorithm ensures that the original control points lie on the surface and allows provisions to be included that give respect to surface characteristics such as breaklines. Based on research conducted at the Ohio State University, the combination of an irregular triangular grid contouring algorithm and interactive computer graphics results in a fast, flexible and easy to use computer contouring program.

INTRODUCTION

In recent years, cartographic work has taken advantage of interactive programming and computer graphics which has yielded the cartographer real time control over the mapping process. This has resulted in a decrease in the time required to produce a map and in many instances allowed a better map and solution to be obtained. Interactive computer graphics have been used to solve a number of cartographic problems. IGAS, a program developed by Ingram and Moellering (1980), has shown the usefulness of interactive computer graphics for editing cartographic data. ICMS, a program developed by Turner and Moellering (1979), has shown the usefulness of interactive computer graphics in the production of choropleth maps. Moellering, Gauthier and Osleeb (1977) have used the approach for analytical cartographic purposes when they developed a program known as TRANPLAN. These programs and many similar ones have greatly increased the power available to cartographers in the handling of cartographic data.

Isarithmic mapping or "contour mapping" is a particular type of mapping that has followed the trend toward the use of the increasingly sophisticated computer programs. An isarithm is defined as "any trace of the intersection of a horizontal plane with a statistical surface" (Robinson, Sale and Morrison, 1978). The theme of the surface may be land elevations, rainfall, temperature, the thickness of rock stratum, etc. Isarithmic mapping is used to display data that meets both the requirements of a statistical surface, that is the data is parametric and meets the continuity assumption. Many computer programs based on different numerical algorithms are currently being used to make isarithmic maps. The sophistication of the output has a wide range. Programs exist that produce line printer maps while others produce higher quality plotter maps.

This paper discusses a computer program, Interactive Contouring from an Irregular Triangular Grid (ICFITG), which is used to produce isarithmic maps. The program has been designed to be easy to use, as well as take advantage of several recent advances in the areas of numerical contouring algorithms and interactive techniques. The program is implemented on the Ohio State University computer system.

BACKGROUND

Interactive cartography has great potential in the field of cartography as it provides the cartographer with methods in a dynamic mode (Moellering, 1980). This allows the cartographer to modify cartographic images and view the results in a near real-time environment through the use of a Cathode Ray Tube (CRT) device interfaced to a computer.

It is possible to make a distinction between the traditional hardcopy map or "real map" and the ephemeral image or "virtual map" viewable on devices such as CRT's (Moellering, 1977, 1980). A real map is a map which has a permanent tangible reality about itself and can be recognized as a map by direct observation. A virtual map, on the other hand, is a map which when displayed looks like a real map, but has no physical reality in the form seen by the map viewer. It is the virtual map that is of great importance to interactive cartographic systems as the cartographer can make many modifications to the virtual map by altering the data underlying the virtual image until he is satisfied and has what he considers a correct image. At that point, the cartographer can commit the virtual map to a real map through the use of some type of plotting device or by hardcopying the CRT image.

Much of the value of interactive cartography has resulted from the man-machine interface (Moellering, 1977). That is, communication between man and machine is carried out in a variety of ways such that a suitable virtual map is produced. The user may "point" with the graphic cursor to a "menu" of commands drawn on the screen and recognized by the system. The user may use the graphic cursor to "point" to specific locations on the virtual map for the purpose of numerical and graphic manipulation. If the user "points" to the virtual map for the purpose of identifying an item, the process is known as "picking". If the user "points" to the virtual map for the purpose of gaining or adding information, the process is known as "locating" (Foley and Wallace, 1974; Ohlson, 1978). The user may also communicate with the system by entering alphanumeric data strings. The system may communicate with the user by printing messages on the CRT screen. The system may also communicate with the user by issuing audible signals that have meaning to the user (Tuerke, 1976). Typically, the ring of a terminal bell is used for this purpose.

Over the past decade or thereabouts, a number of individuals have suggested that human intervention would be advantageous to a numerical contouring program or package (Walters, 1969; Biggin, 1971; Peucker, 1972; Tomlinson, 1972; Hartwig, 1978). Perhaps a quote from Walters (1969), made when projecting toward the future, best emphasizes this:

> "To be effective, such a program must allow the user to make judgements during the preparation or modification of the contoured map to enable the specialist to introduce his background into generation of the final contours. The process of interaction between man and machine requires a general purpose contour program and a trained user to derive optimum results."

Thus, a contouring program should be flexible, allowing many errors to be avoided by selecting the best combination of parameters for the given situation.

Tomlinson (1972) notes some options that might be considered in a contouring program such that flexibility is achieved by human intervention. Worthy of consideration is the ability to override certain values and to blank whole areas as desired or where data is too sparse. Likewise, the ability to automatically identify areas where data is sparse or varied could be useful. An option that allows the plotting of the original data points and their values along with the contours is sometimes desirable. The ability of a contouring program to carry out artistic enhancement is worthy of consideration. This includes the ability to draw contours in varying line weights or as a dashed line. A contouring program should include the capability to add a neatline and the name, location and scale of the area being contoured to the final map.

Recent research concerning contouring programs indicate that there are a number of advantages to carrying out contouring from an irregular triangular grid (Gold et al, 1977; Yoeli, 1977; Peucker et al, 1978; Elfick, 1979; and McCullagh and Ross, 1980). Such advantages are as follows. The original data points are preserved, such that the control points lie on the surface. Provisions are present that give respect to surface characteristics such as breaklines. The grids do not yield more accuracy than is present, which can be the case when a sparse collection of data points is interpolated to a dense rectangular grid. Contouring algorithms that utilize an irregular triangular grid require little computer core space as they are often loaded in sections and do not require a lengthy, time-consuming interpolation phase to construct the grid.

Hence, it is the purpose of ICFITG to combine the advantages of contouring from an irregular triangular grid with those of working in an interactive environment. The program allows the user the opportunity to make decisions that affect the outcome of the final isarithmic map while ICFITG is executing.

THE PROGRAM - "INTERACTIVE CONTOURING FROM AN IRREGULAR TRIANGULAR GRID"

The analytical goal of ICFITG is to allow the user to make judgements during the preparation or modification of an isarithmic map to enable a specialist to introduce his experience into the generation of the final isarithms. This is accomplished by allowing the user to work interactively; such that decisions can be made while ICFITG is executing. The result is an isarithmic map which is better and can be produced more rapidly than an isarithmic map produced manually or by batch oriented computer programs. The features implemented in the program to accomplish this are as follows. The program informs the user of the average surface resolution, the minimum and maximum data points and the standard deviation of the control points. ICFITG incorporates the advantages of an irregular triangular grid and displays the grid for the user to inspect. It allows the user the capability to edit the control points and to enter breakline information by entering extra data points. It allows the user the capability to consider several isarithmic intervals when producing a map. ICFITG allows a virtual map to be saved for later use or modification and allows real map output to be produced.

The program ICFITG is designed around the irregular triangular grid contouring algorithm suggested by Elfick (1979). The Elfick algorithm was selected for several reasons. It includes all the advantages that are present when contouring is carried out from an irregular triangular grid. The algorithm minimizes computer core requirements while at the same time reducing the execution time. As the number of data points increases, the execution time increases linearly as opposed to exponentially. The final triangles file created by the algorithm has data of the same precision as the original data points. The only difference is that the file is structured in a form more suitable for contouring since the relationships between the points and lines of interpolation are incorporated. Finally, the algorithm can be adapted to operate in an interactive setting. This includes the interactive entry of breakline information. Using the algorithm interactively strengthens its overall capability.

The basic logic of ICFITG, shown in Figure 1, is to read and display a set of control points such that they can be manipulated to produce the desired isarithmic map. To accomplish this, the user needs the capability to edit the control points. The editing of the control points allows new points to be added and outdated or erroneous points to be deleted. Editing the control points allows breakline information to be entered in the manner suggested by Elfick (1979). Elfick recommends that breakline information be processed prior to the actual formation of the triangles of the irregular grid by simply scanning along each breakline and adding extra data points by linear interpolation in sectors where it would be likely that a triangle could be formed across a breakline. The user needs the capability to thread isarithms through the grid and display them. The capability is needed to produce a real map of the isarithms. Relative to the above capabilities, the user needs to be able to repeat various parts of the program such that different input parameters can be entered and considered. Throughout the program, the user requires the capability to look at complex areas in detail through the use of "windowing". Likewise, throughout the program, it is necessary to be able to save modified data point sets for later use.

Having identified the sub-tasks involved in the basic logic, various commands can be identified such that, when the commands are issued from the system, the sub-task is carried out. A list of such commands and their accompanying sub-commands is shown in Table 1.

Table No. 1

Command Language

System Prompt	Commands	Subcommands
ICFITG>	DATA	
	POINTS>	ADD
		INTERP
		DELETE
		DISZVAL
		DISALLZ
		REDRAW
		WINDOW
		RESETW
		ENDP
	TRIGRID	
	ISOLINE	
	OVRPNTS	
	OVRTRIG	
	OVRISO	
	SAVE	
	RESTORE	
	WINDOW	
	RESETW	
	ENDI	

Logical Flowchart of ICFITG

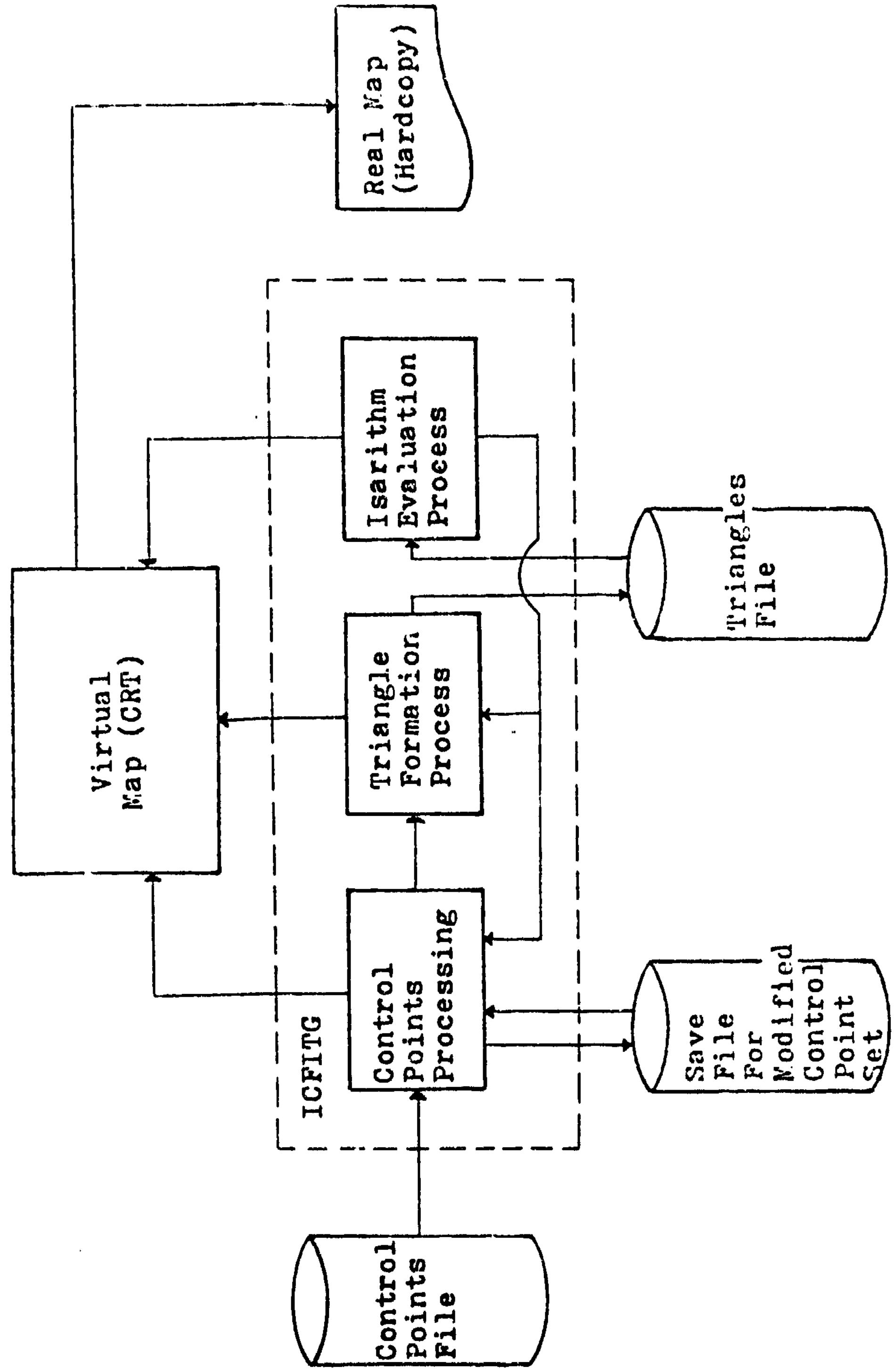

Figure 1

ICFITG's screen design is common throughout the program. This is shown in Figures 2 through 6. The screen is divided into areas in an effort to standardize where the user directs his attention. The communication area is set up on the left. This is where the system solicits questions and where the user types in commands and answers. The map display area is on the right side of the screen, such that it is near the graphic controls. In this area the user views the control points, the triangular grid and the isarithmic map. When a command is issued that invokes the graphic cursor, the cursor is used in the map display area to locate points to be added, deleted, etc. The map display area is outlined such that the user is aware of the area's graphic limits.

Included in the screen design is an area below the map display area used to inform the user of the average surface resolution (ASR). The ASR is calculated based on the sampling theorem which is applied to regular grids for the purpose of determining grid resolution. The sampling theorem states that the sampling interval has to be half the size of the smallest feature to be encoded. The program calculates the average sampling interval in the irregular grid and writes this value, known as the ASR, on the screen. The average sampling interval is the average distance to a nearest neighbor control point from a given control point. The user can use the ASR to get a general feeling for the smallest feature the data can reveal.

Included in the screen design is the legend or heading block area. It is located directly above the map display area, such that the user can easily associate the information contained within each area. Within the legend the user can be provided with title, scale, date, time, the minimum data point z-value, the maximum data point z-value, the standard deviation of data point z-values and the isarithmic interval. The information contained in the legend is useful both during the interactive development of a map and on the final hardcopy map.

The cartographic design for ICFITG can be discussed in terms of the map display area which is bound by a solid neatline. Control points shown in the map display area are identified by small tick marks. When a tick mark's z-value is displayed the value is located to the upper-right of the tick. When a point is added or interpolated to the surface it is displayed as a tick mark with another smaller tick mark placed directly over it and rotated forty-five degrees. When a point is deleted, a small triangle, drawn in a solid line, is displayed superimposed over the points tick mark. When the irregular triangular grid is displayed in the map display area it is shown in a dotted line pattern. When the isarithms are displayed in the map display area they are shown in a solid line. Thus, when both the isarithms and the irregular triangular grid are displayed simultaneously, a proper figure-ground relationship is achieved.

ICFITG is designed to include as many positive communication factors as possible. The system is designed such that the mixing of numeric and alphabetic characters is avoided within a textual string of characters. Likewise, the input of lengthy sequences and the overloading of the user is avoided. ICFITG avoids lengthy delays and allows the user to work at his own pace. It provides proper feedback such that the user's confidence is maintained and error recovery is possible. The system is designed such that the user's ability and the computer's ability are used efficiently. The user directs the system and evaluates the results while the computer presents rapid results and alternatives and performs laborious and repetitive tasks.

The communication means between the user and the system consists of the graphic cursor to pick and locate items on the screen, a command language to instruct the computer and an audible bell to prompt the user. The communication area is restricted to the left side of the screen to standardize the area where the user expects textual interaction. The system prompts the user for input with one ring of the bell. The system identifies errors to the user with three rings and a line of accompanying text. When questions are asked, they are answerable with simple answers in command language or with numeric values. The system's command language is structured to allow a conversational naturalness.

The system ICFITG is implemented on a large computer system at the Ohio State University. At Ohio State, the central processing unit is an Amdahl 470 V6, while the time sharing system used is IBM TSO (Time Sharing Option). ICFITG utilizes the Tektronix 4012 and 4014 storage CRT terminals for interactive graphics and the Tektronix 4631 Hardcopy Unit for real map output. ICFITG is written in two computer languages: Fortran IV and IBM Assembler. The Tektronix Interactive Graphics Library is used to perform all graphics work.

ICFITG SYSTEM OPERATION

In preparation for system operation, the user should try to find a base map or aerial photograph that covers the area in which the work is to be carried out. The user should study this map in an effort to evaluate where possible breaklines might occur. For example, if an isarithmic map is to be produced representing an economic phenomena in an urban area, a possible breakline might occur between the principal city and a wealthy suburb. Or if a climatic subject matter, such as temperature, is to be mapped, the user would be interested in finding out about the location of sharp topographic changes, industrial areas, urban areas and other features that could result in modifying the temperature. In some instances it is not possible to acquire a definitive base map and it is necessary that an aerial photograph be used in substitution. Another useful preparatory step is the compilation of a list of any new or questionable control points and their location.

Upon executing ICFITG, the first task carried out is the display of the program name along with its originator. This information ensures the user that the correct program is running. After this, the CRT display is cleared and a system prompt, ICFITG> , is issued in the communication area awaiting the user to enter a system command (see Table 1). From this point on, the program is unstructured, but several constraints do exist. The control points must be read in, that is, a DATA command issued prior to using the commands POINTS, TRIGRID and SAVE. The irregular triangular grid must be constructed, that is, the command TRIGRID issued prior to using the commands OVRTRI, OVRISO and ISOLINE. The command SAVE, issued to save a set of control points for later use, must be issued prior to using the RESTORE command.

With these constraints in mind, a typical ICFITG session can be described. Normally, the first command that is issued is the DATA command and the control points are read in and displayed on the CRT screen. Next, if editing the control points is necessary, the user can issue the POINTS command and then use the appropriate sub-commands (see Table 1). After the control points are read in and edited if required, an irregular triangular grid can be formed and displayed through the use of the TRIGRID command. An example of such a grid is shown in Figure 2. After the irregular triangular grid is formed, the user can issue a command for the program to thread the isarithms through the grid. If the user would like to see the isarithms and the irregular triangular grid on the CRT screen at the same time, the command OVRISO is used. If the user desires only the isarithms, the command ISOLINE is issued. If the user is threading the isarithms through the grid for the first time, it is probably most desirable to see the isarithms relative to the grid. An example of contours overlaid on to a grid is shown in Figure 3. At this point, the user can evaluate the results to determine if any triangles appear to erroneously cross a breakline. If such a problem does exist, the user can use the WINDOW command to obtain an enlarged view of the area containing the breakline. An example of a "windowed" area is shown in Figure 4. The POINTS command can then be used to edit the area followed by the area being recreated to show the result. Figure 5 shows the area in Figure 4 after the control points are edited to yield additional breakline information, such that no triangles are formed across the breakline. After this the map display area can be reset to full view using the

THE TRIANGLE FILE IS
BEING FORMED.
THE TRIANGLE FORMATION
PROCESS HAS TERMINATED
SUCCESSFULLY.
ICFITG>

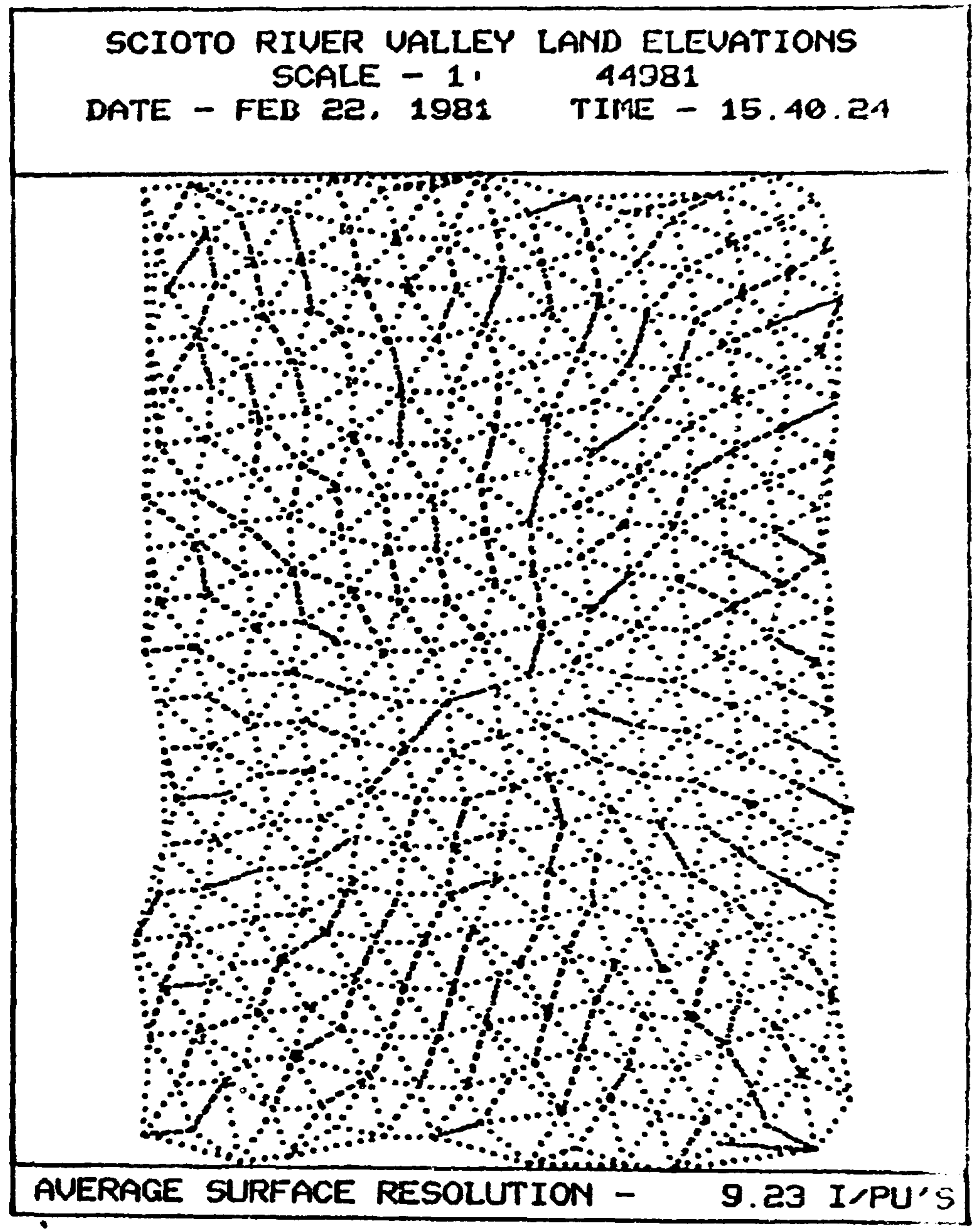

Figure 2

```
THE TRIANGLE FILE IS
BEING FORMED.
THE TRIANGLE FORMATION
PROCESS HAS TERMINATED
SUCCESSFULLY.
ICFITG>
ovriso
ENTER THE ISARITHM UNITS.
feet
ENTER THE INTERVAL.
?
20.
ENTER THE INTERVAL
STARTING LEVEL.
?
760.
ICFITG>
```

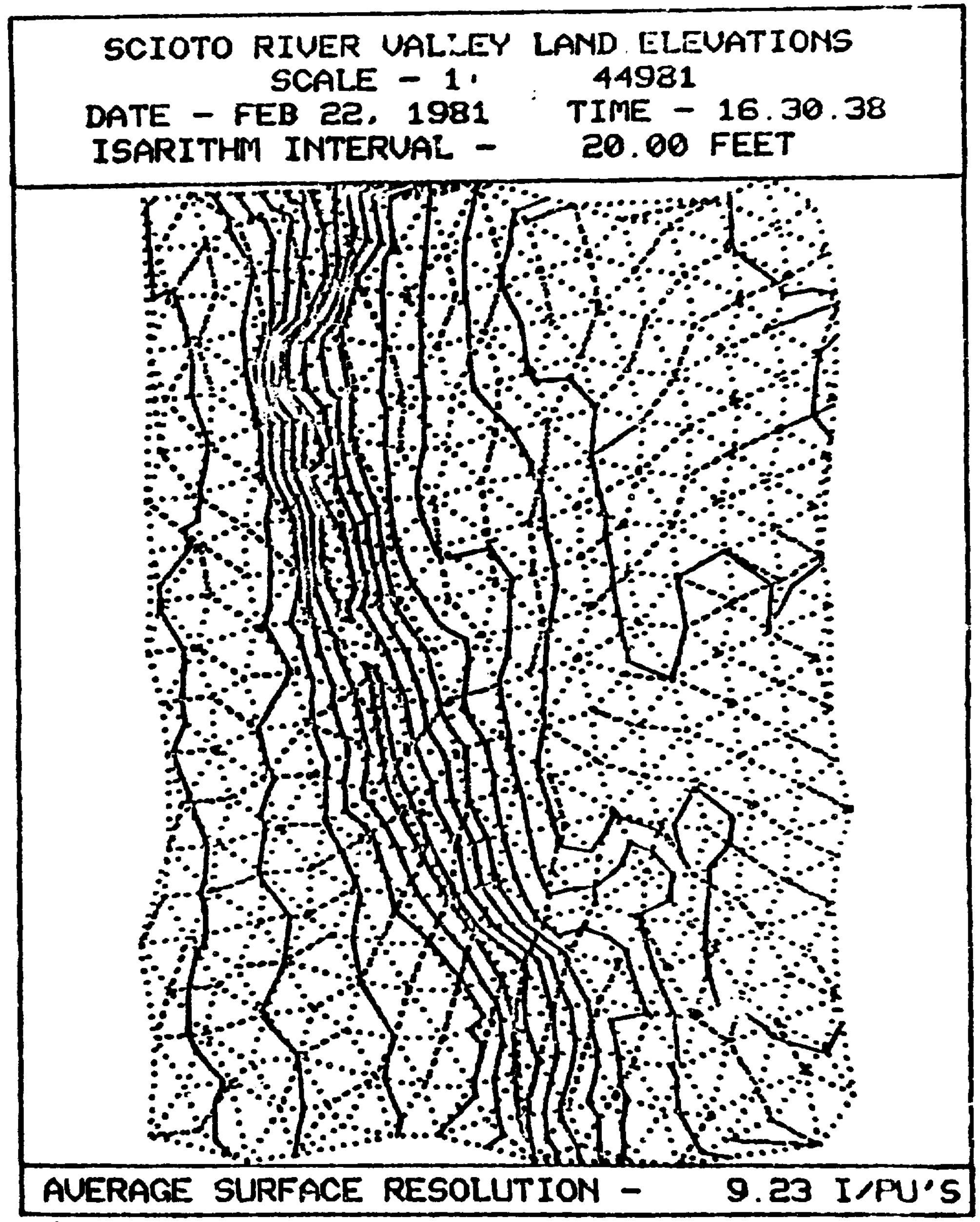

Figure 3

```
THE TRIANGLE FILE IS
BEING FORMED.
THE TRIANGLE FORMATION
PROCESS HAS TERMINATED
SUCCESSFULLY.
ICFITG>
ovriso
ENTER THE ISARITHM UNITS.
feet
ENTER THE INTERVAL.
?
20.
ENTER THE INTERVAL
STARTING LEVEL.
?
760.
ICFITG>
```

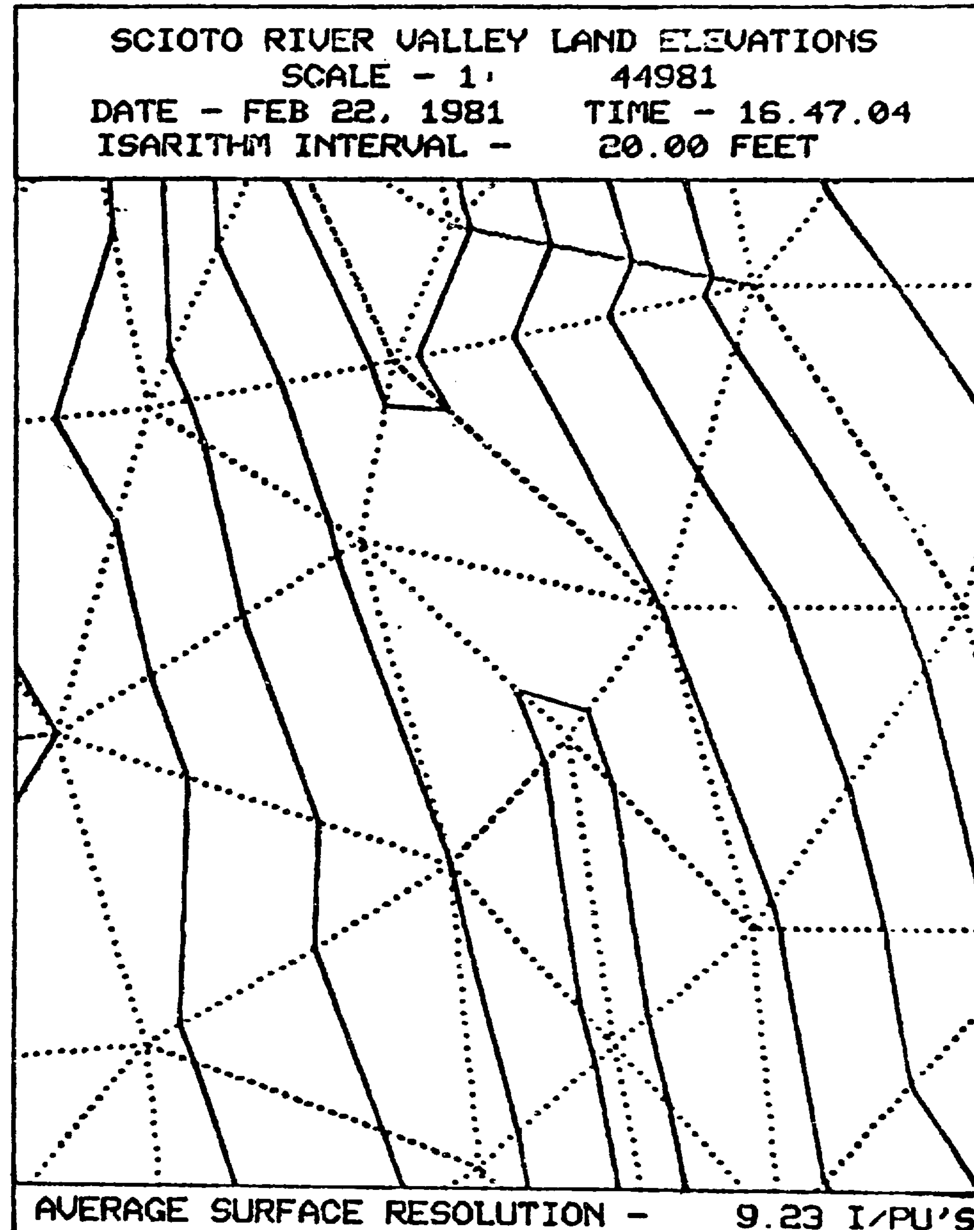

Figure 4

```
THE TRIANGLE FILE IS
BEING FORMED.
THE TRIANGLE FORMATION
PROCESS HAS TERMINATED
SUCCESSFULLY.
ICFITG>
ovriso
ENTER THE ISARITHM UNITS.
feet
ENTER THE INTERVAL.
?
20.
ENTER THE INTERVAL
STARTING LEVEL.
?
760.
ICFITG>
resetw
THE WINDOW IS RESET TO
FULL SIZE.
ICFITG>
trigrid
ENTER Z-VALUE TOLERANCE.
?
.5
ENTER THE HORIZONTAL
TOLERANCE.
?
.05
```

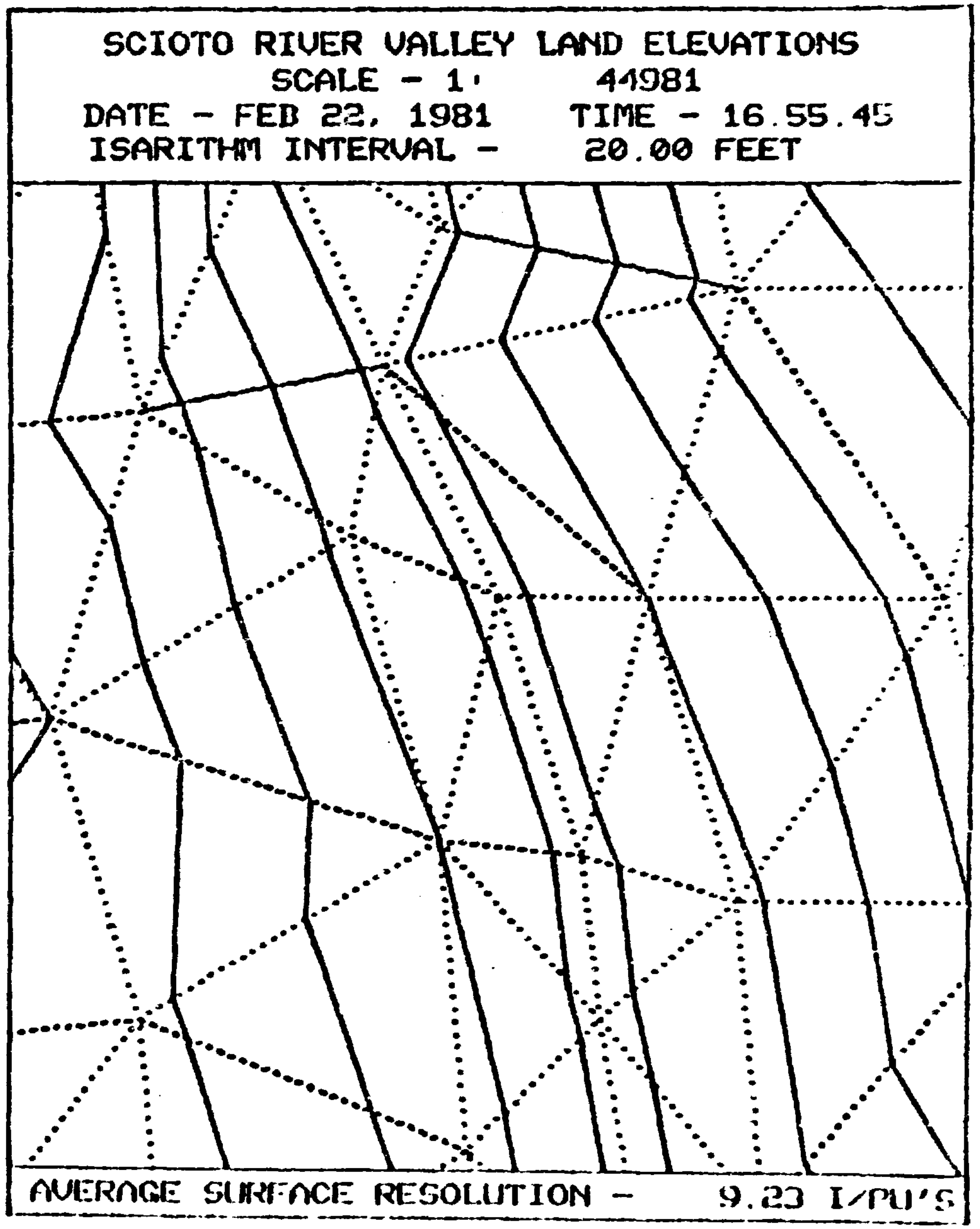

Figure 5

```
THE TRIANGLE FILE IS
BEING FORMED.
THE TRIANGLE FORMATION
PROCESS HAS TERMINATED
SUCCESSFULLY.
ICFITG>
ovriso
ENTER THE ISARITHM UNITS.
feet
ENTER THE INTERVAL.
?
20.
ENTER THE INTERVAL
STARTING LEVEL.
?
760.
ICFITG>
```

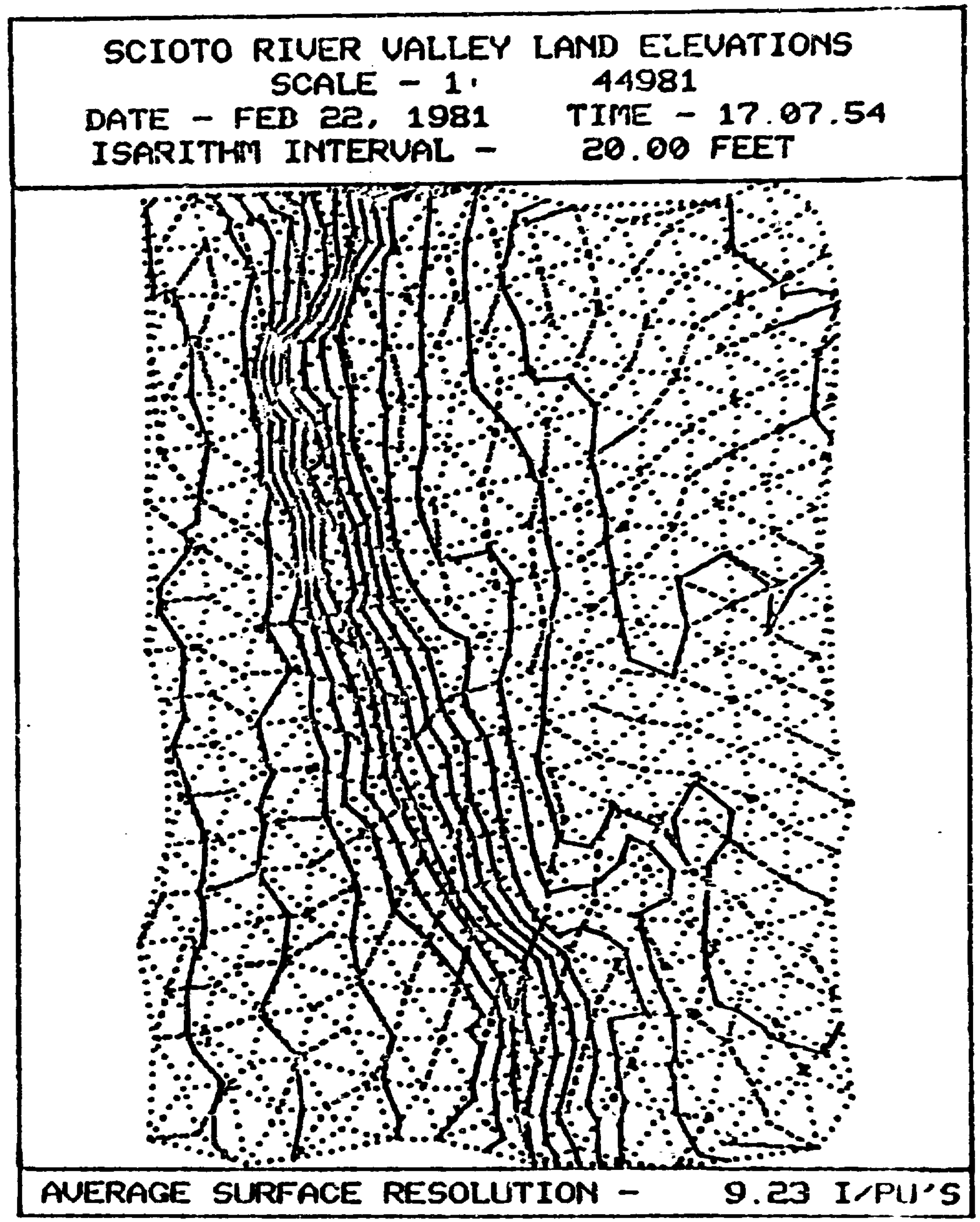

Figure 6

command RESETW. The user can then form a new grid and calculate a new set of isarithms. An example of this is shown in Figure 6. The new isarithms can then be evaluated and the editing process continued until suitable isarithms are found. When found, the user can generate several virtual maps with a different isarithmic interval to evaluate which one is most effective. When one is determined appropriate, the user can commit the virtual map to a real map. Prior to issuing the command ENDI to exit ICFITG the user can issue the SAVE command to save the current control points. This is useful if the control points have been modified since the DATA command was issued. This is a general description of how a typical session with ICFITG might evolve. For a complete discussion and more examples of ICFITG see Brown (1981).

It should be noted that certain commands, upon being issued, request additional input to be made. When the user issues the command TRIGRID, he is requested to enter horizontal and vertical tolerances. If two points lie within the distance specified by the horizontal tolerance, the program inspects the z-values of the two points. If the z-value of the two points then lie within the specified vertical tolerance, the mean of the two points is calculated by the program and the two points represented as one. The purpose of the tolerance entries is to avoid long narrow triangles being formed. Upon entering the tolerances, the program proceeds to form the irregular triangular grid. When the user issues either the command ISOLINE or OVRISO, he is requested to enter the isarithmic units, interval and starting level. The units, such as feet, degrees, etc. are shown along with the interval in the legend area of the CRT screen. The interval and starting level values are used by the program when calculating the isarithms. To help determine the starting level, the user can use the minimum z-value that is displayed when the DATA command is issued.

SUMMARY AND CONCLUSIONS

The cartographic computer program ICFITG allows isarithmic maps to be produced while working in an interactive environment. This is accomplished through the use of virtual images and devices, character commands and responses, and audio signals such that the cartographer can make decisions that affect the outcome of the final map while the program is executing. It is interactive computer graphics that form the link between the speed and repetitive processing power of the computer and the decision making power of the cartographer.

ICFITG incorporates a contouring algorithm which is based on the formation of an irregular triangular grid. The use of such an algorithm allows the user to work directly from data points that are considered random only in the geometric sense. Such "random" points generally have meaning as a result of where they are collected, such as along ridge lines, at extrema, etc. By working directly from the data points, the original control points can be guaranteed to lie on the surface. The use of an irregular triangular grid algorithm allows provisions to be included that give respect to surface characteristics. Unlike a regular grid algorithm, the use of an irregular triangular grid algorithm gives consideration to the distribution of the data. When a regular grid algorithm is used, the grid must be adjusted to the roughest area of the surface and thus be highly redundant in smooth areas of the surface. A further problem avoided by using an irregular grid is the creation of more accuracy than is present. This can be the case when a sparse collection of data points are interpolated into a dense regular grid, thus yielding a false accuracy.

The computer program ICFITG performs as it was designed. The marriage of an irregular triangular grid algorithm and interactive computer graphics has resulted in a fast and strong yet flexible and easy to use system. Through the use of virtual "pick" and "locate" devices control points can be edited. The entry of breaklines is carried out prior to the actual formation of a grid by simply scanning along each breakline and adding extra data points in sectors where it would be likely that a triangle could be formed across a breakline. The program includes provisions that allow "windowing" in areas where the data is complex, such that detail becomes easier to see and work with. ICFITG allows different alternatives to be considered while the program is running such that the user can evaluate results and make decisions rapidly. For instance, the user can produce maps at several different isarithmic intervals and evaluate which one is best. In general, the time required by ICFITG to produce a map is considerably less than the time required to manually produce a map.

Currently a number of functions and further capabilities are being considered for future implementation into ICFITG. Many of these would lead to the enhancement of a final map. Among these are the options to label and smooth the final isarithms. It is felt that both labelling and smoothing should be optional since they may or may not be desirable features in a final map. The given situation would determine the use of them. Likewise, an option that would allow geographic base file (GBF) information to be shown on the virtual and/or real map could be helpful. When shown in the map display area of the CRT screen, it would allow control point and breakline information to be manipulated more easily since it could be viewed relative to GBF information. When shown on a real map, the GBF information would be used for enhancement. Another option being considered is the capability to produce a real map as plotter output. This would complement the current hardcopy capability for real map output. A final consideration being made is to allow breakline information to be entered from a separate auxillary file. It is possible that such an option might make the program more convenient to use. The potential of this has not been fully investigated.

At this time, the program ICFITG may be thought of as a further step in interactive contouring and the use of irregular triangular grid algorithms. Based on the considerations noted above, as well as other possibilities, there exists a potential for more new and exciting research and development in this area.

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